Fitness tracking reveals task-specific associations between memory, mental health, and exercise

Jeremy R. Manning[1,⋆], Gina M. Notaro[1,2], Esme Chen[1], and Paxton C. Fitzpatrick[1]

[1]Dartmouth College, Hanover, NH

[2]Lockheed Martin, Bethesda, MD

[⋆]Address correspondence to jeremy.r.manning@dartmouth.edu

September 17, 2021

Abstract

Physical excercise can benefit both physical and mental well-being. Different forms of exercise (i.e., aerobic versus anaerobic; running versus walking versus swimming versus yoga; high-intensity interval trainiing versus endurance workouts; etc.) impact physical fitness in different ways. For example, running may substantially impact leg and heart strength but only moderately impact arm strength. We hypothesized that the mental benefits of exercise might be similarly differentiated. We focused specifically on how different forms of exercise might related to different aspects of memory and mental health. To test our hypothesis, we collected nearly a century's woth of fitness data (in aggregate). We then asked participants to fill out surveys asking them to self-report on different aspects of their mental health. We also asked participants to engage in a battery of memory tasks that tested their short and long term episodic, semantic, and spatial memory. We found that participants with similar exercise habits and fitness profiles tended to also exhibit similar mental health and task performance profiles.

Introduction

Engaging in physical activity (exercise) can improve our physical fitness by increasing muscle strength (Crane et al., 2013; Knuttgen, 2007; Lindh, 1979; Rogers and Evans, 1993), increasing bone density (Bassey and Ramsdale, 1994; Chilibeck et al., 2012; Layne and Nelson, 1999), increasing cardiovascular performance (Maiorana et al., 2000; Pollock et al., 2000), increasing lung capacity (Lazovic-Popovic et al., 2016) (although see Roman et al., 2016), increasing endurance (Wilmore and Knuttgen, 2003), and more. Exercise can also improve mental health (Basso and Suzuki, 2017; Callaghan, 2004; Deslandes et al., 2009; Mikkelsen et al., 2017; Paluska and Schwenk, 2000; Raglin, 1990; Taylor et al., 1985) and cognitive performance (Basso and Suzuki, 2017; Brisswalter et al., 2002; Chang et al., 2012; Etnier et al., 2006).

The physical benefits of exercise can be explained by stress-responses of the affected body tissues. For example, skeletal muscles that are taxed during exercise exhibit stress responses (Morton et al., 2009) that can in turn affect their growth or atrophy (Schiaffino et al., 2013). By comparison, the benefits of exercise on mental health are less direct. For example, one hypothesis is that exercise leads to specific physiological changes, such as increased aminergic synaptic transmission and endorphin release, which in turn act on neurotransmitters in the brain (Paluska and Schwenk, 2000).

Speculatively, if different exercise regimens lead to different neurophysiological responses, one might be able to map out a spectrum of signalling and transduction pathways that are impacted by a given type, duration, and intensity of exercise in each brain region. For example, prior work has shown that exercise increases acetylcholine levels, starting in the vicinity of the exercised muscles (Shoemaker et al., 1997). Acetylcholine is thought to play an important role in memory formation (Palacios-Filardo et al., 2021, e.g., by modulating specific synaptic inputs from entorhinal cortex to the hippocampus, albeit in rodents;). Given the central role of these medial temporal lobe structures play in memory, changes in acetylcholine might lead to specific changes in memory formation and retrieval.

In the present study, we hypothesize that (a) different exercise regimens will have different, quantifiable impacts on cognitive performance and mental health, and that (b) these impacts will be consistant across individuals. To this end, we collected a year of fitness tracking data from each of 113 participants. We then asked each participant to fill out a brief survey in which they self-evaluated several aspects of their mental health. Finally, we ran each participant through a battery of memory tasks, which we used to evaluate their memory performance along several dimensions. We examined the data for potential associations between memory, mental health, and exercise.

Results

- exploratory analysis (correlations)
  - Memory-memory
  - fitness-fitness
  - survey-survey
  - (fitness + survey)-memory
- predictive analysis (regressions)
  - Predict memory performance on held-out task from other tasks
  - Predict memory performance on each task using fitness data
  - Predict memory performance on each task using survey data
- Reverse correlations: look at recent changes versus baseline trends
  - Fitness profile that predicts performance on each task (barplots + timelines)
  - Fitness profile for each survey demographic (barplots + timelines)
    - Select out mental health demographics (based on meds, stress levels)

Discussion

- summarize key findings
- correlation versus causation
- what can vs. can't we know? we can identify correlations, but not causal direction– e.g. we cannot know whether exercise *causes* mental changes versus whether people with particular neural profiles might tend to engage in particular exercise behaviors. that being said, we *can* separate out baseline tendencies (e.g., how people tend to exercise in general) versus recent changes (e.g., how they happened to have exercised prior to the experiment).
- related work (exercise/memory, exercise/mental health), what this study adds
- future direction: towards customized physical exercise recommendation engine for optimizing mental health and mental fitness

Methods

Experiment

Participants

Tasks

Intake survey.

Free recall.

Naturalistic recall.

Foreign language flashcards.

Spatial learning.

Fitness tracking using Fitbit devices

Processing Fitbit data

Raw metrics.

Comparing recent versus baseline measurements.

Exploratory correlation analyses

Imputation and interpolation of missing data.

Regression-based prediction analyses

Reverse correlation analyses

Acknowledgements

We acknowledge useful discussions with David Bucci, Emily Glasser, Andrew Heusser, Avigail Bartolome, Lorie Loeb, Lucy Owen, and Kirsten Ziman. Our work was supported in part by the Dartmouth Young Minds and Brains initiative. The content is solely the responsibility of the authors and does not necessarily represent the official views of our supporting organizations. This paper is dedicated to the memory of David Bucci, who helped to inspire the theoretical foundations of this work. Dave served as a mentor and colleague on the project prior to his passing.

Data and code availability

All analysis code and data used in the present manuscript may be found here.

Author contributions

Concept: J.R.M. Implementation: G.M.N. Analyses: G.M.N., E.C., and P.C.F. Writing: J.R.M.

Competing interests

The authors declare no competing interests.

References

Bassey, E. J. and Ramsdale, S. J. (1994). Increase in femoral bone density in young women following high-impact exercise. *Osteoporosis International*, 4:72–75.

Basso, J. C. and Suzuki, W. A. (2017). The effects of acute exercise on mood, cognition, neurophysiology, and neurochemical pathways: a review. *Brain Plasticity*, 2(2):127–152.

Brisswalter, J., Collardeau, M., and René, A. (2002). Effects of acute physical exercise characteristics on cognitive performance. *Sports Medicine*, 32:555–566.

Callaghan, P. (2004). Exercise: a neglected intervention in mental health care? *Psychiatric and Mental Health Nursing*, 11(4):476–483.

Chang, Y. K., Labban, J. D., Gapin, J. I., and Etnier, J. L. (2012). The effects of acute exercise on cognitive performance: a meta-analysis. *Brain Research*, 1453:87–101.

Chilibeck, P. D., Sale, D. G., and Webber, C. E. (2012). Exercise and bone mineral density. *Sports Medicine*, 19:103–122.

Crane, J. D., MacNeil, L. G., and Tarnopolsky, M. A. (2013). Long-term aerobic exercise is associated with greater muscle strength throughout the life span. *The Journals of Gerontology: Series A*, 68(6):631–638.

Deslandes, A., Moraes, H., Ferreira, C., Veiga, H., Silveira, H., Mouta, R., Pompeu, F. A. M. S., Coutinho, E. S. F., and Laks, J. (2009). Exercise and mental health: many reasons to move. *Neuropsychobiology*, 59:191–198.

Etnier, J. L., Nowell, P. M., Landers, D. M., and Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research: Brain Research Reviews*, 52(1):119–130.

Knuttgen, H. G. (2007). Strength training and aerobic exercise: comparison and contrast. *Journal of Strength and Conditioning Research*, 21(3):973–978.

Layne, J. E. and Nelson, M. E. (1999). The effects of progressive resistance training on bone density: a review. *Medicine and Science in Sports and Exercise*, 31(1):25–30.

Lazovic-Popovic, B., Zlatkovic-Svenda, M., Durmic, T., Djelic, M., Saranovic, D., and Zugic, V. (2016). Superior lung capacity in swimmers: some questions, more answers! *Revista Portuguesa de Pneumologia*, 22(3):151–156.

Lindh, M. (1979). Increase of muscle strength from isometric quadriceps exercises at different knee angles. *Scandinavian Journal of Rehabilitation Medicine*, 11(1):33–36.

Maiorana, A., O'Driscoll, G., Cheetham, C., Collis, J., Goodman, C., Rankin, S., Taylor, R., and Green, D. (2000). Combined aerobic and resistance exercise training improves functional capacity and strength in CHF. *Journal of Applied Physiology*, 88(1565–1570).

Mikkelsen, K., Stojanovska, L., Polenakovic, M., Bosevski, M., and Apostolopoulos, V. (2017). Exercise and mental health. *Maturitas*, 106:48–56.

Morton, J. P., Kayani, A. C., McArdle, A., and Drust, B. (2009). The exercise-induced stress response of skeletal muscle, with specific emphasis on humans. *Sports Medicine*, 39:643–662.

Palacios-Filardo, J., Udakis, M., Brown, G. A., Tehan, B. G., Congreve, M. S., Nathan, P. J., Brown, A. J. H., and Mellor, J. R. (2021). Acetylcholine prioritises direct synaptic inputs from entorhinal cortex to CA1 by differential modulation of feedforward inhibitory circuits. *Nature Communications*, 12(5475):doi.org/10.1038/s41467–021–25280–5.

Paluska, S. A. and Schwenk, T. L. (2000). Physical activity and mental health. *Sports Medicine*, 29(3):167–180.

Pollock, M. L., Franklin, B. A., Balady, G. J., Chaltman, B. L., Fleg, J. L., Fletcher, B., Limacher, M., na, I. L. P., Stein, R. A., Williams, M., and Bazzarre, T. (2000). Resistance exercise in individuals with and without cardiovascular disease. *Circulation*, 101:828–833.

Raglin, J. S. (1990). Exercise and mental health. *Sports Medicine*, 9:323–329.

Rogers, M. A. and Evans, W. J. (1993). Changes in skeletal muscle with aging: effects of exercise training. *Exercise and Sport Sciences Reviews*, 21:65–102.

Roman, M. A., Rossiter, H. B., and Casaburi, R. (2016). Exercise, ageing and the lung. *European Respiratory Journal*, 48:1471–1486.

Schiaffino, S., Dyar, K. A., Ciciliot, S., Blaauw, B., and Sandri, M. (2013). Mechanisms regulating skeletal muscle growth and atrophy. *The febs Journal*, 280(17):4294–4314.

Shoemaker, J. K., Halliwill, J. R., Hughson, R. L., and Joyner, M. J. (1997). Contributions of acetylcholine and nitric oxide to forearm blood flow at exercise onset and recovery. *Vascular Physiology*, 273(5):2388–2395.

Taylor, C. B., Sallis, J. F., and Needle, R. (1985). The relation of physical activity and exercise to mental health. *Public Health Reports*, 100(2):195–202.

Wilmore, J. H. and Knuttgen, H. G. (2003). Aerobic exercise and endurance. *The Physician and Sportsmedicine*, 31(5):45–51.